16208

Live Modeling of a DynaVision SPR-02 Sensor For Rangefinding Application

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ABSTRACT

Terrain sensing in high clutter environments commonly encountered in battlefield operations continues to be an operational concern. Clutter, such as battlefield debris, dust, smoke, and obscurants make the use of non-touch terrain sensing solutions difficult. In the first step to obtaining a non-touch sensor solution, live modeling of a DynaVision SPR-02 Intelligent Single Point Sensor will be conducted. This sensor is a laser source non-contact optical displacement measurement system. Scanning is accomplished by projecting a continuous light beam onto a surface and detecting the wave image of this beam on a Charge Coupled Device (CCD) array.

The SPR-02 was mounted on a cart. The cart is part of a 24-foot rail system where it can be pulled at a constant velocity. While the cart is moving at a constant velocity, the sensor detects the distance to the ground and sends the information to the data acquisition system. Data has been collected for two separate test arrangements. The first test arrangement investigates four different surfaces. The second test arrangement investigates five different surfaces. These tests serve as a platform for live modeling by simulating varying levels of vegetation and terrain. For the first arrangement, the sensor is oriented parallel to the test surface. For the second arrangement, the sensor is angled off the vertical axis to look forward in front of the cart system. These tests demonstrate the sensor's capability to accurately sense the distance to the surfaces tested.

In general, work of this nature is being conducted in support of the Grizzly program. To clear a minefield, the Grizzly has a requirement for its plow to accurately maintain a user-selected depth. For this to be accomplished, the shape, or contour, of the terrain must be known. A "no-touch" sensor solution, situated outside of the blast cone, would be more survivable than the current configuration and therefore allow the Grizzly to continue its mission more effectively.

This work represents a preliminary effort. Future work using this sensor will include investigating several different terrains, in different environmental conditions, and at varying angles and heights. The "no-touch" sensor solution for the Grizzly program will likely include more than one type of sensor. Therefore, once testing of the SPR-02 is complete, work on other systems such as radar or acoustic will ensue.

INTRODUCTION

The Grizzly vehicle is a combat mobility system capable of conducting in-stride breaches of complex linear obstacles. It also incorporates countermine and counterobstacle capabilities and features a full-width mine clearing blade. The current Grizzly configuration includes a tactile sensor as part of this system. There is a possibility of damaging this sensor and this presents a risk. As a risk mitigation effort, the TARDEC Terrain Sensing Laboratory is exploring technologies as an improvement to the tactile sensor.

The first alternative being explored is the DynaVision SPR-02 Intelligent Single Point Sensor. This sensor is a laser source non-contact optical displacement measurement system. Scanning is accomplished by projecting a continuous light beam onto a surface and detecting the wave image of this beam on a Charge Coupled Device (CCD) array.

The information presented in this report is with respect to live modeling in the laboratory. Outdoor tests will be conducted at a later date.

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LIVE MODELING PROCEDURE FOR PERPENDICULAR ORIENTATION OF SPR-02 SENSOR

The SPR-02 was mounted on a cart where the sensor is first placed parallel to the surface to be tested. The cart is part of a 24-foot rail system where it can be pulled at a constant velocity (see figures 1 and 2).

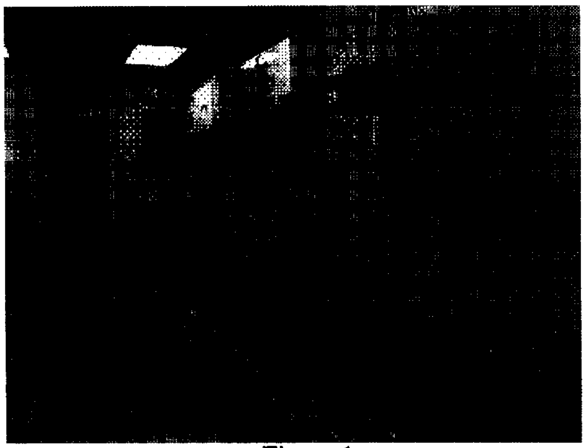

Figure 1

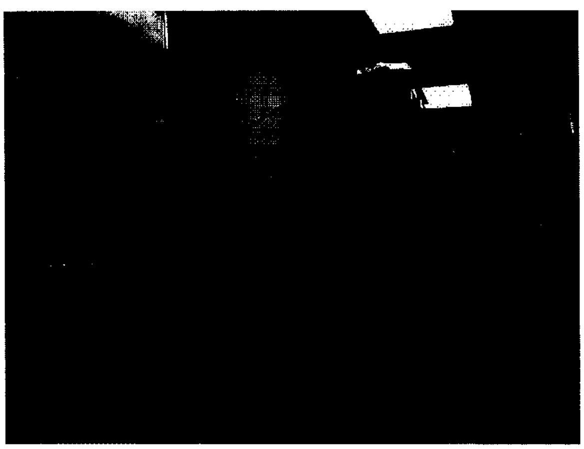

Figure 2

The cart was pulled along a 24-foot rail system using a DC motor and a pulley system.

Four different terrains were used during the perpendicular sensor orientation testing. First, a truth measurement was made to determine the distance from the sensor to the terrain. Truth measurements for the aforementioned terrains are the distance the terrain is from the sensor. In the cases of terrain 1 and 2 this distance is obvious. The distance measurement for terrain 3 (Astroturf) is taken to be the distance to the turf bed (as opposed to the turf blades). Similarly, the truth distance to the sod is taken to be the sod bed. These last two distances are taken to be truth because, for the Grizzly mine clearing mission, this is the area of interest. Second, cart velocity information was recorded. Then, while keeping the cart velocity constant, the cart moved over the terrain to be tested and distance and time data was collected. This data was collected using Labview data acquisition environment. Data for each terrain was collected for five different runs.

Descriptions of the terrains tested are shown below along with their application to the live modeling concept. The first terrain, the baseline, is a flat surface. It is a constant distance away from the sensor for the length of the rail system. Terrain 1 is a heavy gauge rubber (Oilrite MIL-153265F) covering the base of the rail system. The second through the fourth terrains are placed on this rubber surface. The second terrain consisted of three blocks of varying height and a ramp (see figure 3). This was done to simulate the sensor reaction to terrain variations and battlefield debris. The steps were composed of a rough sponge-like material and the ramp was composed of a sanded wood surface. The different surfaces provided some basis for confidence that the sensor could react to changing surfaces without affecting the output of the range measurement.

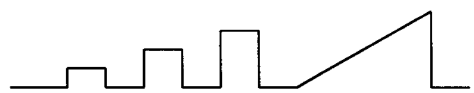

Figure 3
Terrain 2 profile

Terrain 3 was a Flair doormat AstroTurf by Monsanto. The purpose of live modeling this surface was to take a first look at a rougher surface having some of the characteristics of very short grass. Finally, terrain 4 was live Kentucky Blue Grass. Live grass was used in order to include some effects such as moisture, vegetation color, and a first test for the sensor to handle the random nature of blade orientation and a rough, densely vegetative surface.

PERPENDICULAR MEASUREMENTS

On average, 4000 data points were collected for each run. A run on the dynamic test track with the cart and pulley system was generally on the order of 20 feet or less, meaning that 17 raw data points were being collected every inch the cart traveled. A range of values were collected for each surface and the average used for each run. Data from all the runs exhibited a normal distribution where the mean, median, and mode were fairly close to one another (see Figure 3).

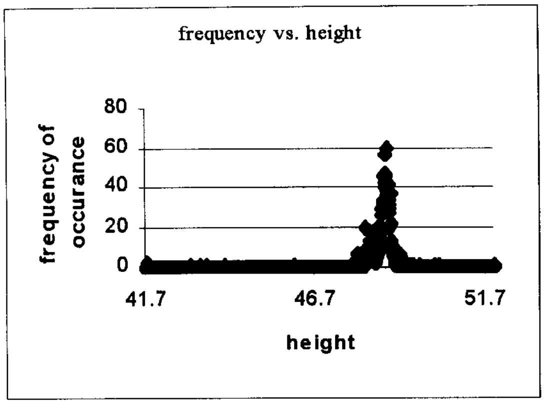

Figure 3

Note how tightly the data is output as a range. This gives confidence that the data being gathered is very repeatable.

Following are the average distances from the sensor collected for each run. All measurements are in inches and are +/- .01".

Terrain 1- Rubber baseline
Run 1: 48.83
Run 2: 48.83
Run 3: 48.83
Run 4: 48.83
Run 5: 48.83

Terrain 2- Steps and Ramp

	Step1	Step2	Step 3	Ramp (beginning/end)
Run 1:	46.83	44.91	41.83	48.13/40.66
Run 2:	46.83	44.92	41.83	48.12/40.63
Run 3:	46.84	44.93	41.84	48.12/40.59
Run 4:	46.83	44.92	41.83	48.14/40.71
Run 5:	46.83	44.92	41.84	48.12/40.63

Terrain 3- Astro Turf
Run 1: 48.69
Run 2: 48.70
Run 3: 48.70
Run 4: 48.69
Run 5: 48.71

Terrain 4- Kentucky Blue Grass
Run 1: 46.75
Run 2: 46.76
Run 3: 46.62
Run 4: 46.64
Run 5: 46.74

RESULTS

The above measurements were then compared to the truth measurements made for each terrain. All truth measurements are in inches, are +/- 1/32" for terrains 1 and 2, and +/- .01" for terrains 3 and 4. The results are as follows:

Terrain 1- Rubber baseline

	Data Avg.	Truth	|Delta|	|% Difference|
Run 1:	48.83	48.813	.0175	.036
Run 2:	48.83	48.813	.0175	.036
Run 3:	48.83	48.813	.0175	.036
Run 4:	48.83	48.813	.0175	.036
Run 5:	48.83	48.813	.0175	.036

Terrain 2- Steps and Ramp

	Data Avg.	Truth	|Delta|	|% Difference|
Run 1:				
step 1:	46.83	46.88	.045	.096
step 2:	44.91	44.94	.028	.061
step 3:	41.83	41.69	.143	.342
ramp:				
begin	48.13	48.125	.005	.010
end	40.66	40.375	.285	.706
Run 2:				
step 1:	46.83	46.875	.045	.096
step 2:	44.92	44.9375	.018	.039
step 3:	41.83	41.6875	.143	.342
ramp:				
begin	48.12	48.125	.005	.010
end	40.63	40.375	.255	.632
Run 3:				
step 1:	46.84	46.875	.035	.075
step 2:	44.93	44.9375	.008	.017
step 3:	41.84	41.6875	.153	.366
ramp:				
begin	48.12	48.125	.005	.010
end	40.59	40.375	.215	.533
Run 4:				
step 1:	46.83	46.875	.045	.096
step 2:	44.92	44.9375	.018	.039
step 3:	41.83	41.6875	.143	.342
ramp:				
begin	48.14	48.125	.015	.031
end	40.71	40.375	.335	.830
Run 5:				
step 1:	46.83	46.88	.045	.096
step 2:	44.92	44.94	.018	.039
step 3:	41.84	41.69	.153	.366
ramp:				
begin	48.12	48.13	.005	.010
end	40.63	40.38	.255	.632

Terrain 3- Astro Turf

	Data Avg.	Truth	|Delta|	|% Difference|
Run 1:	48.69	48.75	.06	.12
Run 2:	48.70	48.75	.05	.10
Run 3:	48.70	48.75	.05	.10

Run 4: 48.69	48.75	.06	.12
Run 5: 48.71	48.75	.04	.08

Terrain 4- Kentucky Blue Grass

Data Avg.	Truth	|Delta|	|% Difference|
Run 1: 46.75	47.61	.86	1.81
Run 2: 46.76	47.61	.85	1.79
Run 3: 46.62	47.61	.99	2.08
Run 4: 46.64	47.61	.97	2.04
Run 5: 46.74	47.61	.87	1.83

DISCUSSION

Inspection of the above results reveals that the data is both fairly consistent and accurate. In general, the measurements obtained are consistent from run to run, for the same surface, and vary on the order of hundredths of an inch. The accuracy of the measurements is demonstrated by comparison with truth measurements, on the order of hundredths of an inch.

Terrain 4, the Kentucky Blue Grass, is the exception to the above. Variations are on the order of tenths of an inch both between runs and when compared with the truth measurement. A couple of reasons exist for this larger variation. First, we used live sod. When purchased, the sod was rolled. Prior to measurements, we racked the sod to lift the blades. During measurements, it is possible that blades that were partially lifted, continued to straighten, or they may have re-flattened themselves. This would account for the variation between the runs and would be characteristic of any live material used. Second, truth was taken to be the sod bed. This is because this is the area of interest for the Grizzly vehicle. Of course, sod has blades of grass and the sensor will pick up laser reflections from various parts of the blades. This accounts for the variation from truth. Overall, SPR-02 saw what was there. If one looks at an inversion of the data, it looks like sod (see figure 4)

LIVE MODELING PROCEDURE FOR SLANT RANGE ORIENTATION OF SPR-02 SENSOR

The SPR-02 was mounted on a cart where the sensor is placed at 51 degrees off the vertical axis of the surface. Instead of the 50 inches off the ground in the initial set of testing just described, the laser height was increased to the maximum height the laboratory would allow and the laser was angled forward to project the beam in front of the cart. This was done to examine the sensor's ability to predictively sense terrain in front of a moving vehicle.

The angle in which the laser was mounted reduced the length of the effective test area on the 24-foot rail system to approximately 14 feet (see figures 1 and 4)

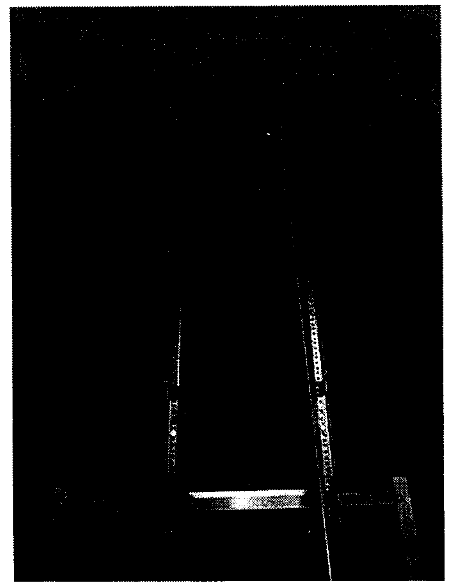

Figure 4

Once again, the cart was pulled along a 24-foot rail system using a DC motor and a pulley system. The slant range orientation of the sensor is shown here.

Five different terrains were tested using the same procedure as the perpendicular testing. First, a truth measurement was made to determine the distance from the sensor to the terrain. Second, cart velocity information was recorded. Then, while keeping the cart velocity constant, the cart moved over the terrain to be tested and distance and time data was collected. This data was collected using Labview data acquisition environment. Data for each terrain was collected for five separate trials.

Descriptions of the terrains tested are as follows. The first terrain, the baseline, is a flat surface. It is a constant distance away from the sensor for the length of the rail system. Terrain 1 is a heavy gauge rubber (Oilrite MIL-153265F) covering the base of the rail system. The second through the fourth terrains are placed on this rubber surface. The second terrain was a light green Astroturf which had simulated grass texture approximately 0.15" in height. The third terrain was a dark forest green Astroturf which had simulated grass blades approximately 0.5" in height. The fourth terrain was a live 2" Kentucky Bluegrass sod. Finally, terrain 5 was live 2" Kentucky Blue Grass sod superimposed with a moderate amount vegetation taken from a nearby field which varied in depth from one to three feet high (shown below). This vegetation was composed of six different types including both tall and thin, and shorter leafy varieties of plant growth.

Figure 5

In the case of terrain 1 this distance is obvious. The distance measurement for terrains 2 and 3 is taken to be the distance to the turf bed (as opposed to the turf blades), while terrains 4 and 5 are taken to be the distance to the sod bed (as opposed to the blades of grass). Similarly, the truth distance to the sod is taken to be the sod bed.

MEASUREMENTS

Over 1000 data points were collected for each run. A range of values was collected for each surface and the average used for each run. Data from all the runs exhibited a normal distribution where the mean, median, and mode were fairly close to one another. Following are the average distances from the sensor collected for each run. All measurements are in inches and are +/- .01".

Terrain 1- Rubber baseline
Run 1: 132.73
Run 2: 132.61
Run 3: 132.65
Run 4: 132.68
Run 5: 132.69

Terrain 2- Light Green Astroturf (slightly elevated off the baseline surface by a board)
Run 1: 131.18
Run 2: 131.36
Run 3: 131.30
Run 4: 131.29
Run 5: 131.32

Terrain 3-Dark Forest Green Astroturf
Run 1: 131.45
Run 2: 131.50
Run 3: 131.58
Run 4: 131.48
Run 5: 131.27

Terrain 4- 2" Deep (average) Kentucky Blue Grass
Run 1: 129.34
Run 2: 129.31
Run 3: 129.31
Run 4: 129.28
Run 5: 129.33

Terrain 5- 2" Deep (average) Kentucky Blue Grass sod superimposed with random vegetation varying from 1 to 3 feet in height. Due to the height of the vegetation, a simple filter was used to capture the maximum slant range. This is a deviation from the other tests because if the raw data was averaged, the error would be significantly higher from ground truth. At this point the testing procedure was changed in order to deal with the complex nature of performing live simulation of a field or meadow. Since the goal is to find the maximum slant range, an optimization process was used to get sufficiently close to ground truth and yet provide enough output data to update the terrain height every few inches.

Normal Laboratory Lighting

	10%*	5%*
Run 1:	130.19	130.39
Run 2:	130.17	130.45
Run 3:	130.21	130.46
Run 4:	130.20	130.45
Run 5:	130.15	130.35

Laboratory lighting plus two 500-Watt Halogen area lights directed at simulated field.

	10%*	5%*
Run 6:	130.06	130.31
Run 7:	129.84	130.16
Run 8:	130.13	130.36
Run 9:	130.13	130.35
Run 10:	130.22	130.44

Almost zero ambient light in an enclosed room for the same simulated field.

	10%*	5%*
Run 11:	130.05	130.25
Run 12:	130.12	130.38
Run 13:	130.12	130.47
Run 14:	129.98	130.18
Run 15:	130.13	130.53

- *The 10% and 5% values were a very basic filter applied to the raw data. Ten and five percent of the longest slant range points were filtered out of the entire data set obtain the overall average distances above.

RESULTS

The above measurements were then compared to the truth measurements made for each terrain. All truth measurements are in inches, are +/- 1/32" for terrain 1, and +/- .01" for terrains 2 through 5. The results are as follows:

Terrain 1- Rubber baseline

	Data Avg.	Truth	|Delta|	|% Diff|	%BDP*
Run 1:	132.73	132.59	0.14	0.11	55/1531
Run 2:	132.61	132.59	0.02	0.01	40/1569
Run 3:	132.65	132.59	0.06	0.05	70/1677
Run 4:	132.68	132.59	0.09	0.07	69/1644
Run 5:	132.69	132.59	0.10	0.07	60/1676

Terrain 2- Light Green Astroturf

	Data Avg.	Truth	|Delta|	|% Diff|	%BDP*
Run 1:	131.18	131.14	0.04	0.03	38/1070
Run 2:	131.35	131.14	0.21	0.17	50/1152
Run 3:	131.30	131.14	0.14	0.12	52/1141
Run 4:	131.29	131.14	0.13	0.11	47/1115
Run 5:	131.32	131.14	0.18	0.14	56/1163

Terrain 3- Dark Forest Green Astroturf

	Data Avg.	Truth	|Delta|	|% Diff|	%BDP**
Run 1:	131.45	131.43	0.02	0.02	88/982
Run 2:	131.50	131.43	0.07	0.05	93/1641
Run 3:	131.58	131.43	0.15	0.11	92/1631
Run 4:	131.48	131.43	0.05	0.03	93/1677
Run 5:	131.27	131.43	0.16	0.12	93/1704

Terrain 4- 2" Deep Kentucky Blue Grass Sod

	Data Avg	Truth	|Delta|	|% Diff|	%BDP**
Run 1:	129.34	131.38	2.04	1.58	47/1158
Run 2:	129.31	131.38	2.07	1.60	47/1074
Run 3:	129.31	131.38	2.07	1.60	47/1059
Run 4:	129.27	131.38	2.11	1.63	46/1130
Run 5:	129.33	131.38	2.05	1.59	43/1169

Terrain 5- Kentucky Blue Grass superimposed with 1 to 3 feet of vegetation.

Normal Laboratory Lighting Conditions

	Data Avg*	Truth	|Delta|	|% Diff|	%BDP**
Run 1:	130.19	131.38	1.19	0.92	38/1549
Run 2:	130.17	131.38	1.21	0.93	30/1463
Run 3:	130.21	131.38	1.17	0.90	40/1546
Run 4:	130.20	131.38	1.18	0.91	46/1561
Run 5:	130.15	131.38	1.23	0.95	43/1411

Laboratory lighting plus two 500-Watt Halogen area lights directed at simulated field at a range of 5 feet.

	Data Avg*	Truth	|Delta|	|% Diff|	%BDP**
Run 6:	130.06	131.38	1.32	1.01	42/1457
Run 7:	129.84	131.38	1.54	1.19	44/1470
Run 8:	130.13	131.38	1.25	0.96	47/1455
Run 9:	130.13	131.38	1.25	0.96	45/1391
Run 10:	130.22	131.38	1.16	0.89	44/1349

*Represents the percentage of bad data points where the laser received insufficient return light to register a value within its operational range of 16 to 168 inches. The number of total data points taken for the trial is also shown to give perspective of sampling density.

**Note that the data presented here uses the 10% filter which the least restrictive filter of the filters tested (i.e. where 5% is stricter than 10%). As the filter becomes more restrictive, there are fewer data points to average and the sampling rate output of the system decreases.

Almost zero ambient light in an enclosed room for the same simulated field.

	Data Avg*	Truth	|Delta|	|% Diff|	%BDP**
Run 11:	130.05	131.38	1.33	1.02	44/1060
Run 12:	130.12	131.38	1.26	0.97	43/1221
Run 13:	130.12	131.38	1.26	0.97	34/1289
Run 14:	129.98	131.38	1.40	1.08	36/1355
Run 15:	130.13	131.38	1.25	0.96	33/1240

DISCUSSION

Inspection of the above results reveals that the data is both fairly consistent and accurate. In general, the measurements obtained are consistent from run to run, for the same surface, and vary on the order of one-tenth of an inch or less. The accuracy of the measurements is demonstrated by comparison with truth measurements. The variation here was significantly higher than the perpendicular testing. However, the next stage of this effort will include the development of data filters, which should improve the accuracy concerns. It should be noted that in terrains 1 through 4 no filters were used.

Terrain 1, the baseline Oilrite surface, was very promising in that the accuracy error was generally within 0.1%. Although there was more error in the baseline test for the slant range data, the magnitude of the error was considered negligible for a rangefinding application. It was noted that there were a relatively high percentage of bad data points, and it is assumed that this is due to the textured surface of the Oilrite.

Terrain 2 and 3, the light green and dark forest green astroturf respectively, also provided very accurate slant range distances. It was noted that the percentage of bad

data points jumped from approximately 50% for light green to 90% for deep forest green astroturf. Since the laser operates at a frequency of 685 nanaometers (nm), which is deep red in color, the deep forest green is the most difficult color to return light to the SPR-02 receiver. In effect, much the initial light energy is absorbed. This is a known effect for lasers using this frequency range. Although good data points are highly accurate, the forest green astroturf posed a concern that there would not be a sufficient number of points to effectively identify terrain variations in a timely manner.

Terrain 4, the Kentucky Blue Grass, is the exception to the above. The slant range errors for this surface were found to be just over 2" for the majority of the data. The reason is that this was fresh sod which had just been unrolled for the test. The blades of grass were wet, very lush and a deeper green. During measurements, it is possible that since the grass density was so thick and matted down from being in a sod roll, the laser was unable to penetrate the upper layer of the grass the vast majority of the time. This would account for the large error that was measured but would be characteristic of any live material used. Hence, the laser had a difficulty penetrating the blades of grass and therefore returned values which were consistent with the height of the grass above the contour of the terrain. The data was very repeatable however, and variations are on the order of tenths of an inch both between runs and when compared with the truth measurement. It was determined that fresh sod is probably not a very representative terrain for live modeling efforts.

Terrain 5, the 2" Kentucky Blue Grass sod superimposed with 1 to 3 feet of fresh vegetation to create a simulated field in the laboratory, yielded some very promising results. The sod blades were raked so that the blades were oriented upright. This more accurately reflects what would commonly be found in nature. The vegetation that was added was carefully placed along the line of the laser path as the cart was propelled forward for a test. In this way, the laser was forced to deal with the very complex problem of penetrating vegetation to get an accurate slant range distance. Although the laser can't actually penetrate the vegetation, the maximum sampling on this sensor is 667 hertz which allow many of the data samples to include the slant range distance to the ground and through the vegetation. The data for these trial runs provided errors on the order of 1.2 inches.

CONCLUSION

The results of this live modeling indicate that the output of the SPR-02 sensor accurately reflect the terrain that is present. The sensor's performance is promising for vehicle application. Considering the slant range error of 1.2 inches in the worst case laboratory situation (i.e. terrain 5 slant range), the corresponding terrain height error is in the 0.7 to 0.8-inch range. The results of this test in particular merit further investigation through field test to ascertain if this accuracy level can be maintained in outdoor conditions that the Grizzly vehicle might experience. With a better filter used in the data acquisition process, the range data being output from the data should increase the output frequency of accurate data. Modifications to the sensor may also make it easier to see the terrain contour. The possibility exists to combine this sensor data with another type of sensor such as radar or acoustic sensor to achieve a robust output for a wide variety of ambient conditions.